Intelligent Control Reaches the Factory Floor

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NIST
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Technology Administration, U.S. Department of Commerce

ISD
Intelligent Systems Division
Manufacturing Engineering Laboratory

Outline

- Trends in Intelligent Control
- A definition of Intelligent Control
- Applications on the Factory Floor
  - Improvements to Existing Processes
  - Enabling New Processes
  - Materials Handling
  - Interoperability

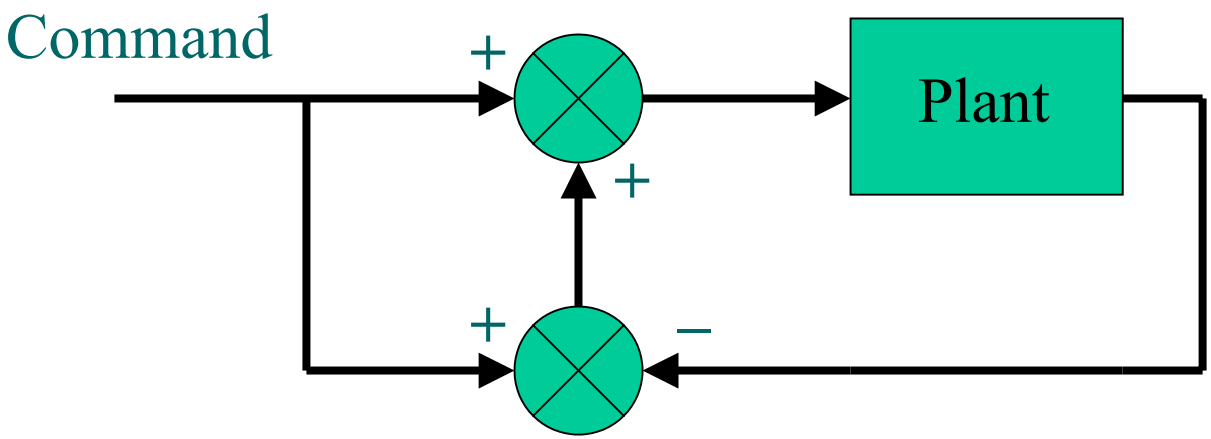
Trends

- Increases in “intelligence” in manufacturing in the past 20 years have been in design and in planning
- In the next 20 years we predict a substantial change in intelligence at the unit process (individual machine) level, with great resulting increases in productivity
  - Example: factor of ten increase in machine tool productivity
  - Example: moving toward the “12 month” car
- This trend is a result of enabling technology plus user value plus open architectures
- Underlying driver is Moore’s Law

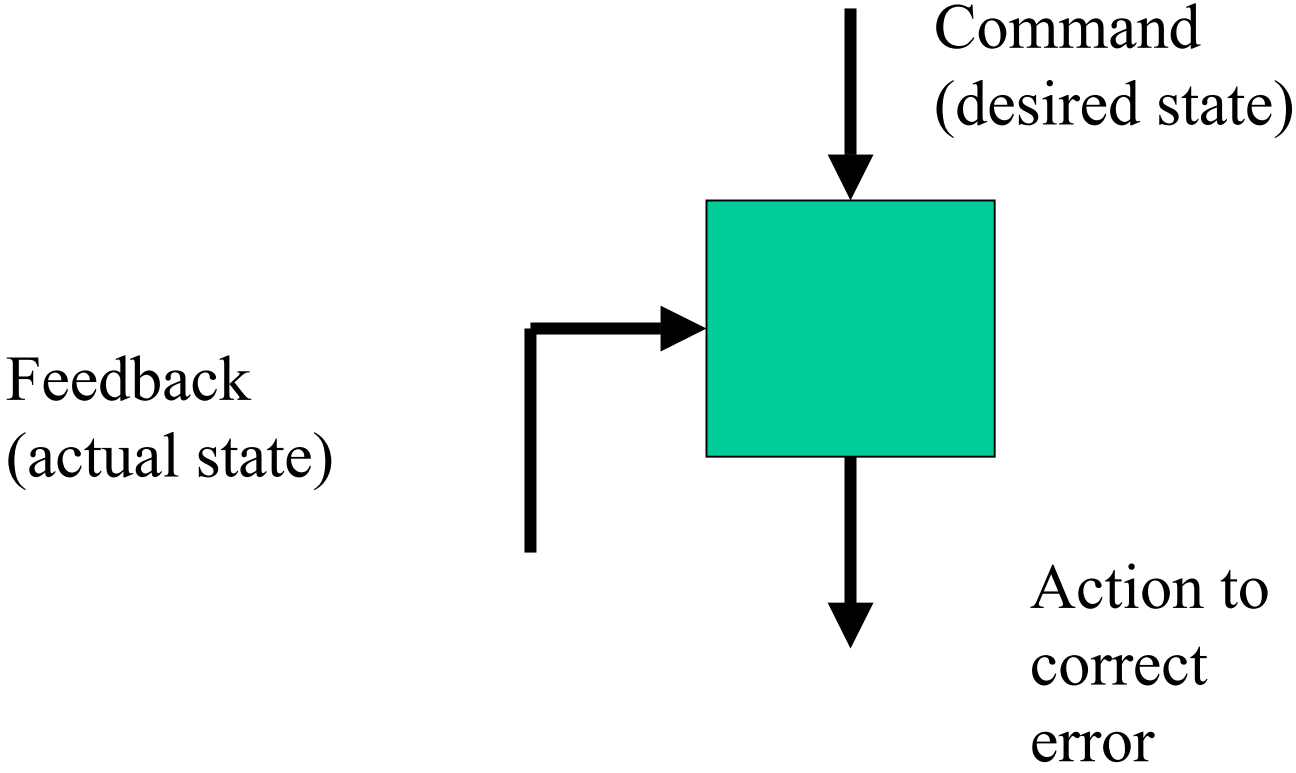
What is "Intelligence" in Intelligent Control?

- Systems which are
  - Non-linear
  - Adaptive
  - Goal-Oriented
  - Knowledge Based
  - Autonomous
  - Capable of Learning
  - Able to deal with uncertainty
  - Able to deal with symbolic reasoning…
- All involve model based sensing and model based control

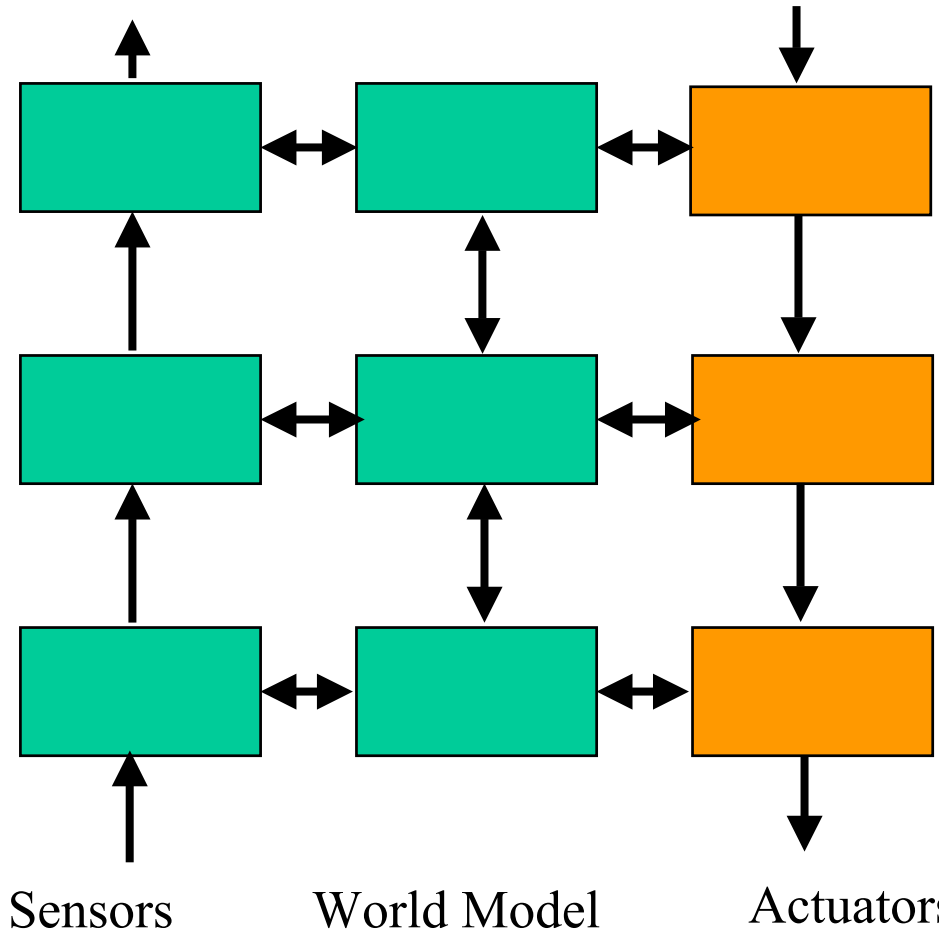
Closed Loop Control



Closed Loop Control



Control of Complex Systems



Typical Machine Control

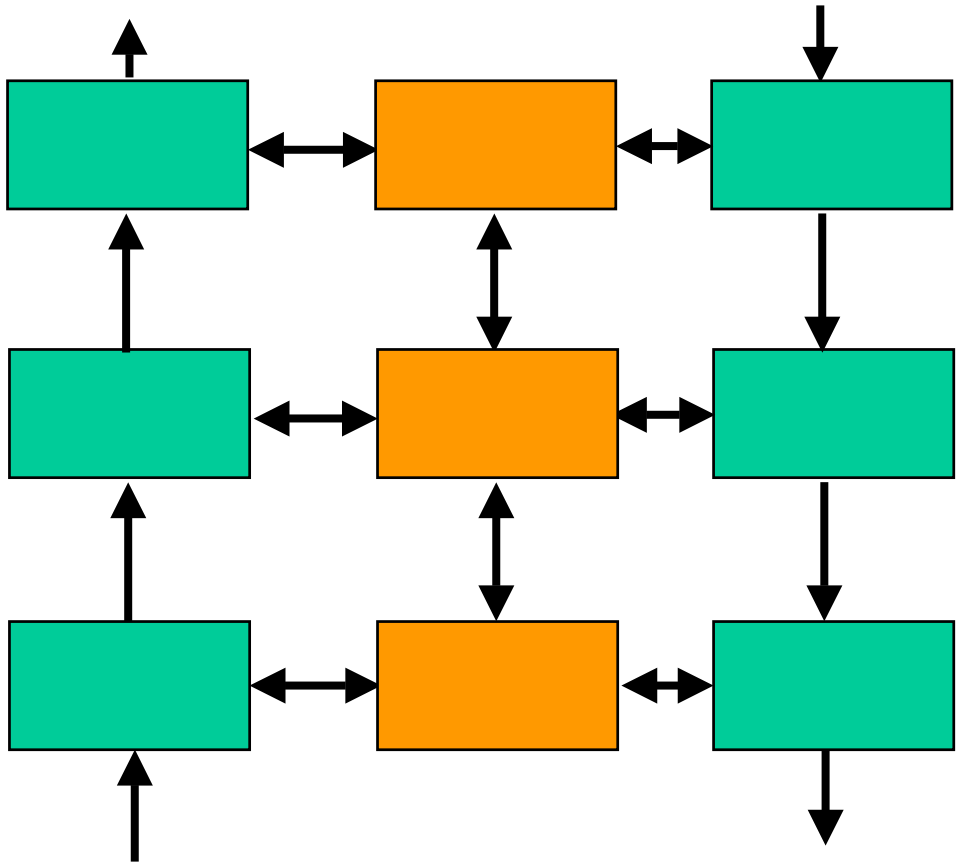
Transitioning to Intelligent Control

Knowledge Engineering

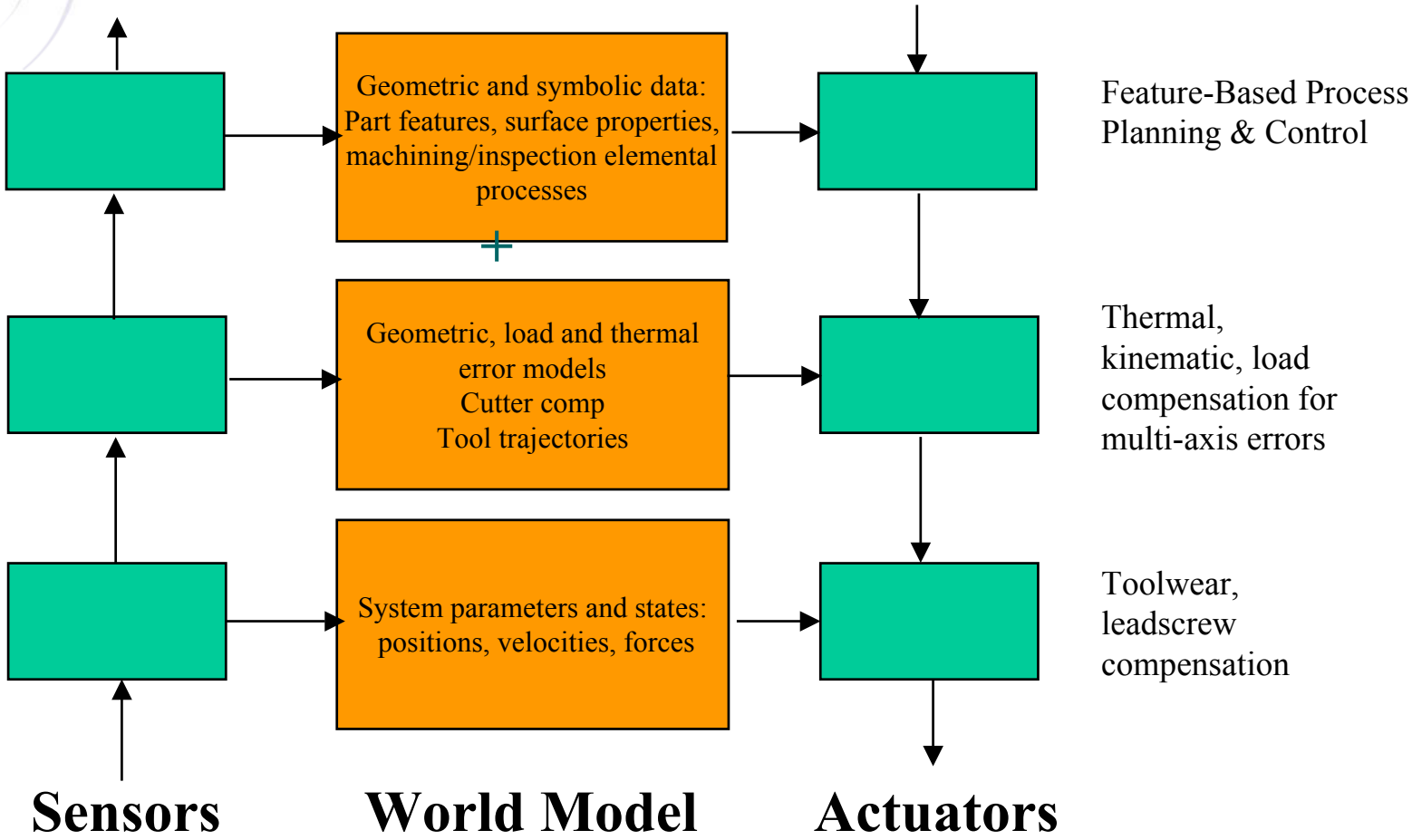
Symbolic data: rules, models, ontologies, skills

Iconic/geometric data: relationships in space and time

Parameters: gains, coefficients



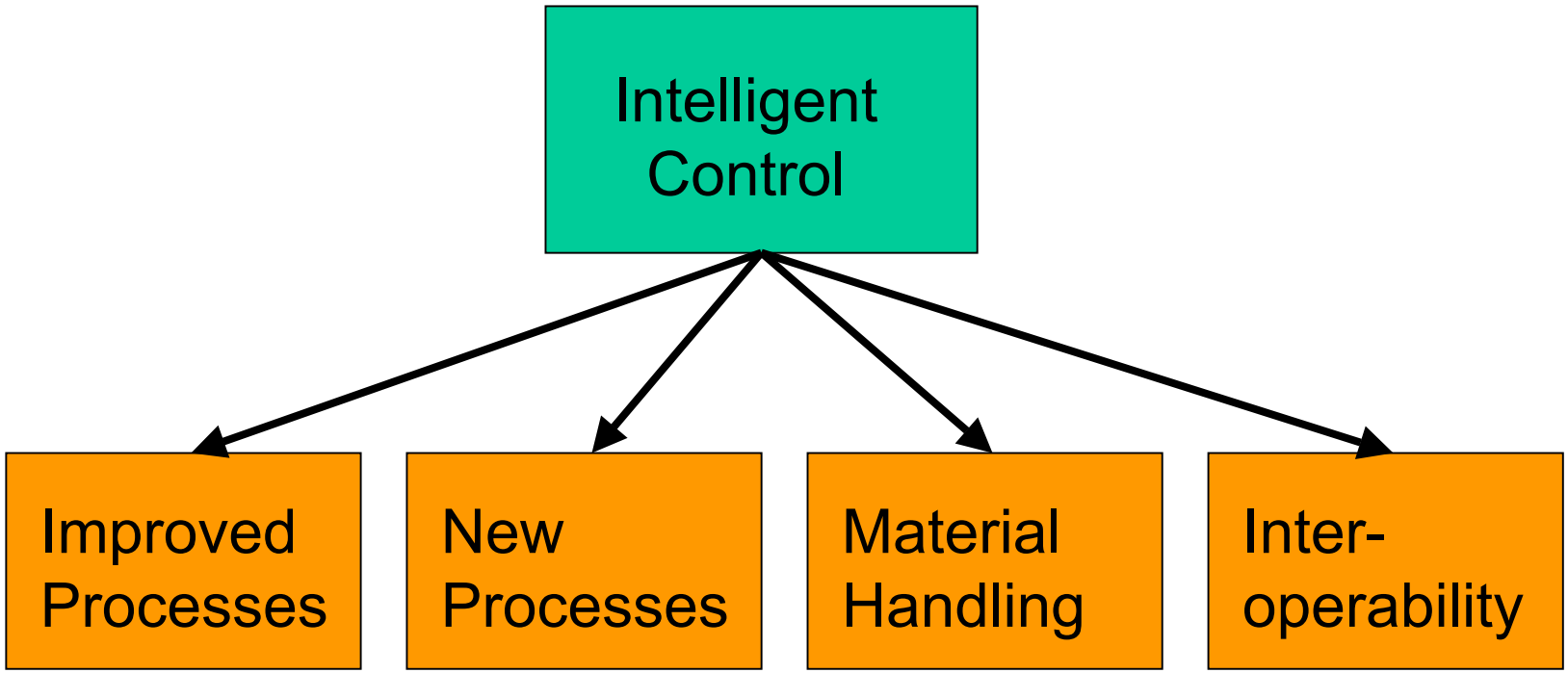
Machine Tool Control Example



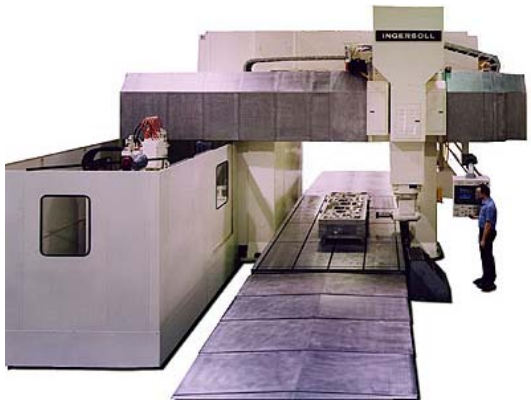
Intelligent Control

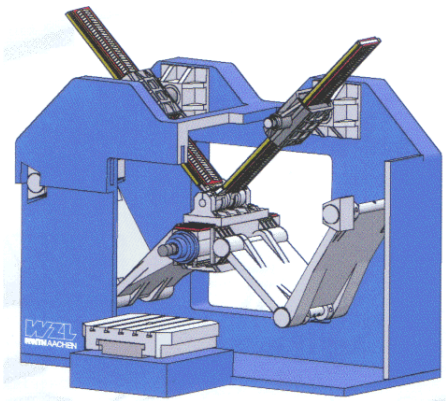
- Appropriate control system
- Appropriate sensors
- Model of the system to be controlled to allow
  - Model based perception
  - Model based control

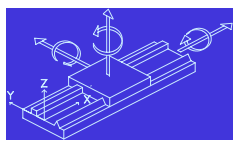
Applications



Characterization and Performance Improvement of Machining Systems



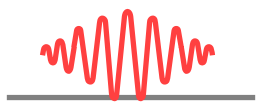




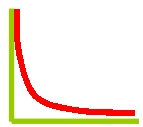
Geometric Errors

Thermal Errors

Stiffness



Machine Dynamics

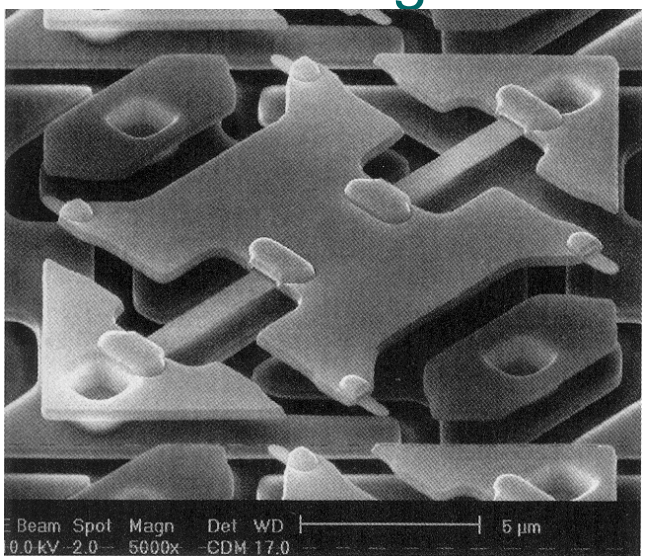


Contouring

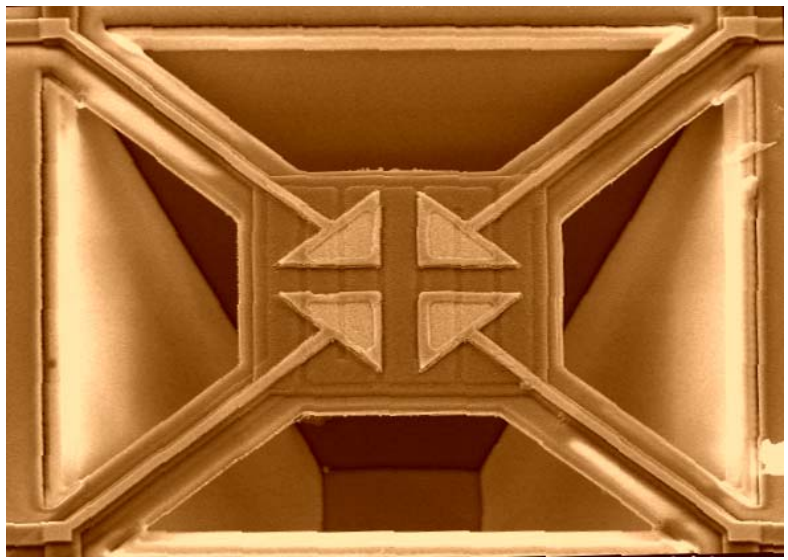
Noise

Reliable and Inexpensive Sensors

- Micro-Electro-Mechanical Systems (MEMS)- mechanical sensors integrated with associated electronics



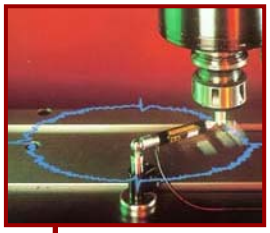
Bending and Twisting Cantilevers: acceleration and force sensors



Suspended Membranes: Temperature, pressure, humidity, flow rate, and sound pressure level sensors

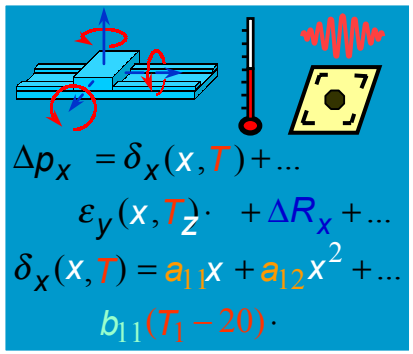
Closed-loop Machining Systems

Performance Evaluation

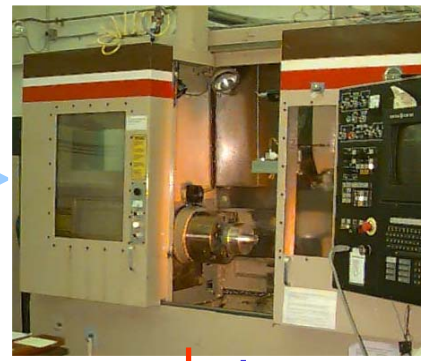


Performance Data

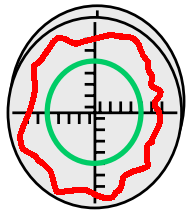
Error Model



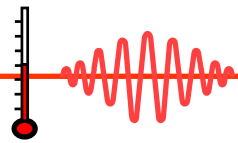
Compensation



Parts

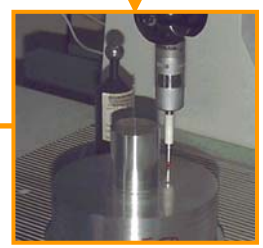


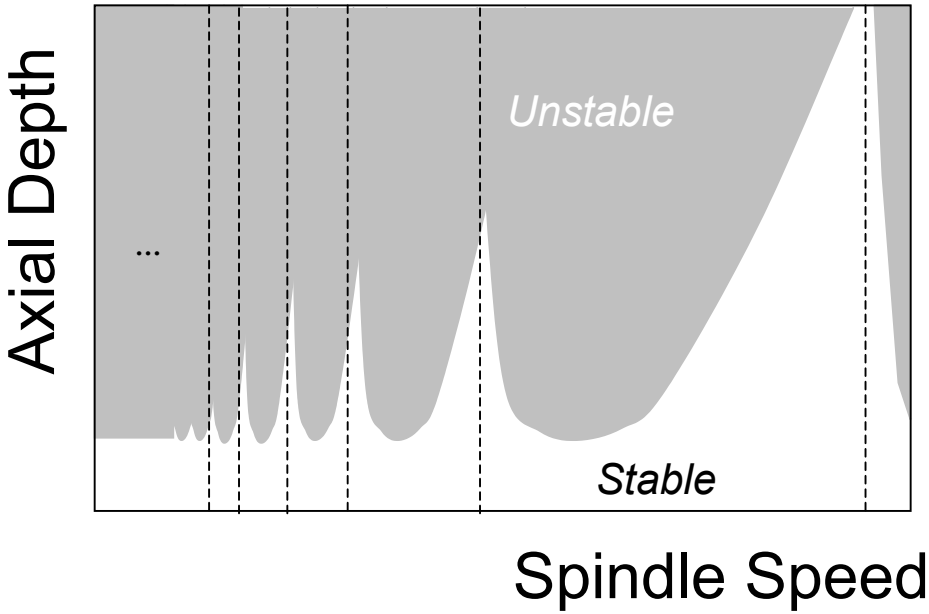
In-Process Sensor Data



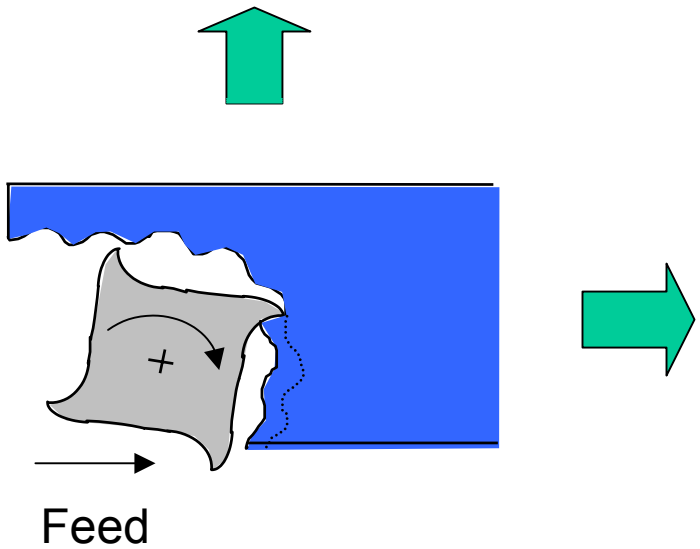
Process-Intermittent Inspection Data

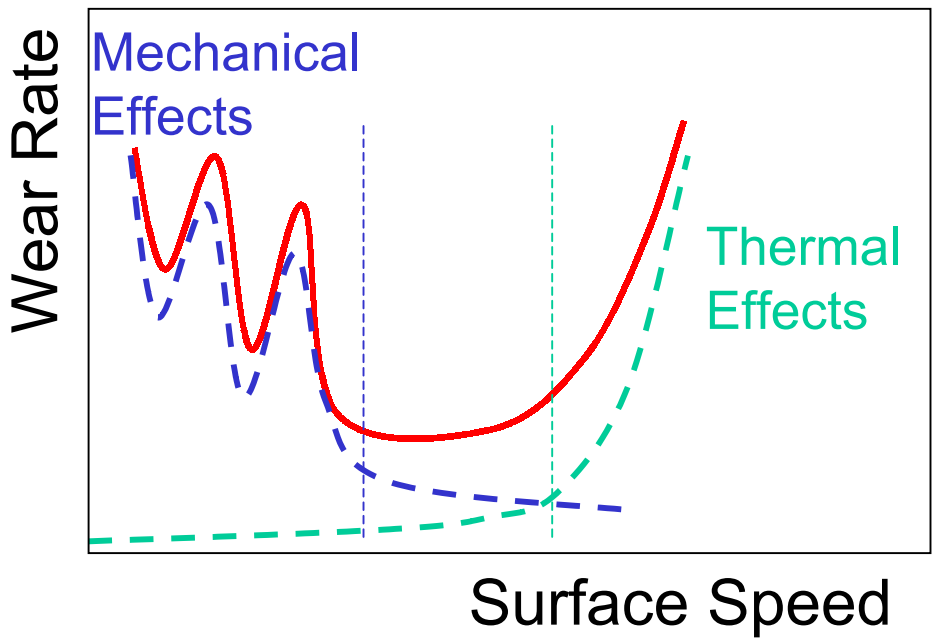
Post-Process Inspection Data





Physics-based models of high speed machining



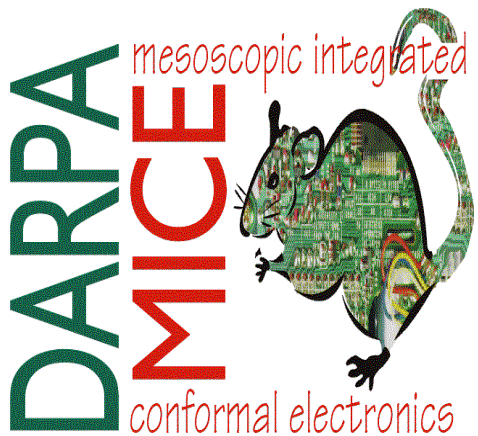


Impact

- Order of Magnitude increase in cutting speed
- Factor of Five increase in accuracy

New Processes

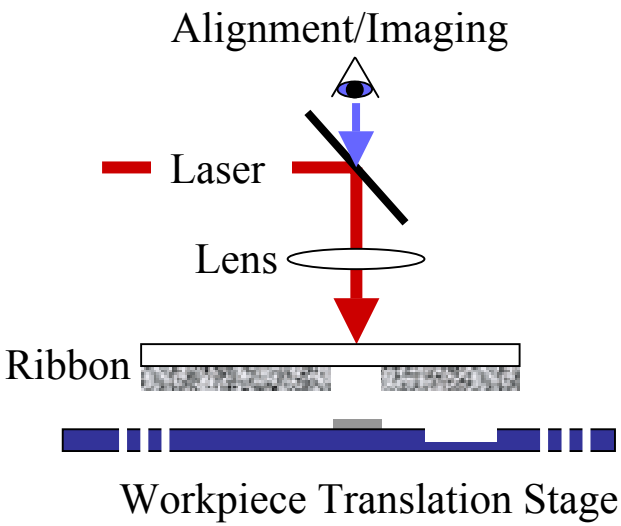
- Solid Freeform Fabrication
- Manufacturing at meso, micro, and nano scales
  - Laser and Ion Beam Processes
  - MEMS (Lithography)
  - LIGA
  - Electroplating
  - Ink jet
  - ...



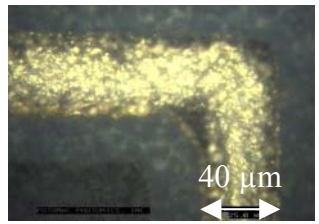
Mesoscale and Microscale Devices: in production

- Ball point pens, watches
- Hearing aids, pacemakers
- Fuel injectors
- RF Tags
- Surface mount electronics
- CD read heads
- Computer disk read/write heads
- Fiber optic connectors and switches
- Smart toys

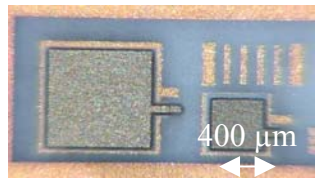
Matrix Assisted Pulsed Laser Evaporation Direct Write, MAPLE DW



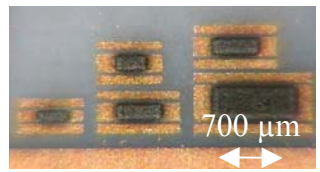
Au Conductors



$BaTiO_3$ Capacitors

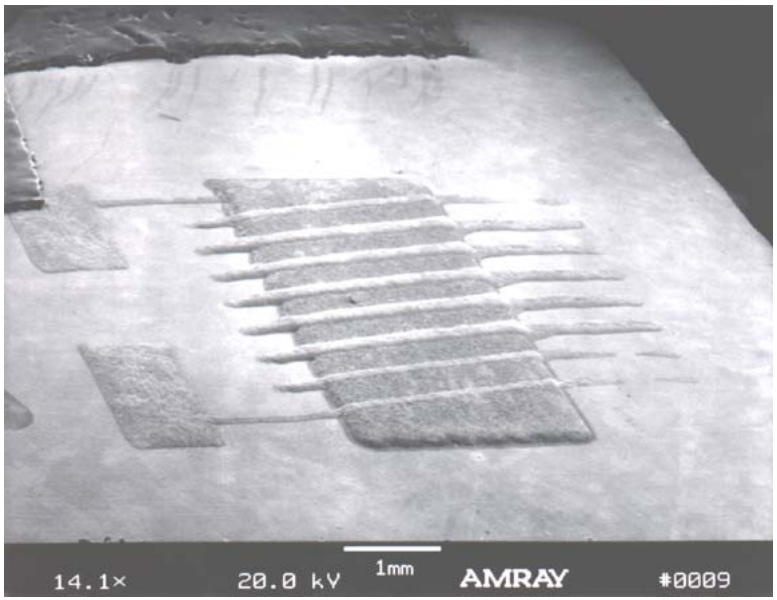


Nichrome Resistors

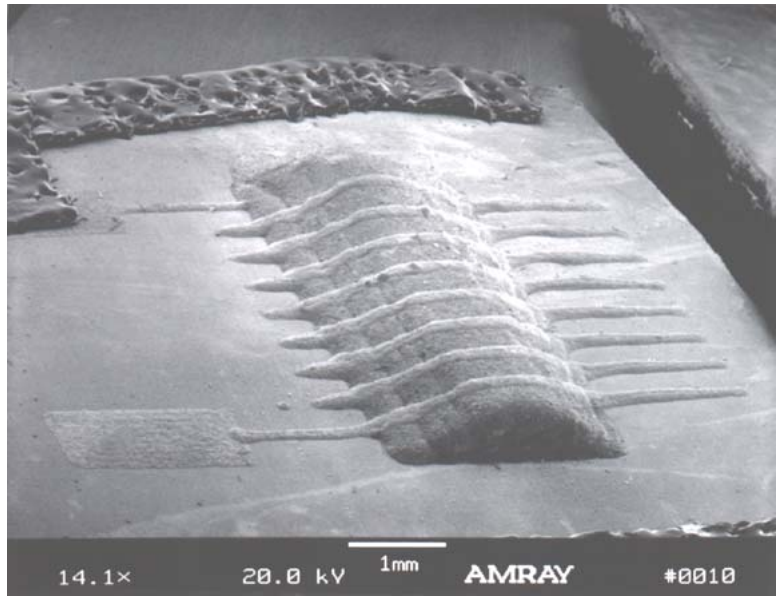


Complex 3-D Structures From Direct-Write Processes

Flat Core Inductor



Multilayer Core Inductor



- **Multilayer core was made by sequentially depositing seven discrete layers**
- **Printed height ~ 400 μm**

Sandia National Laboratories

DARPA

Impact

- New processes require process control together with positioning
- New processes are in many cases difficult to control
- Model based controls incorporating chemistry and physics are required
- Markets are growing rapidly and will have fundamental impact on global market positions by 2025

DOD Autonomous Ground Vehicle Programs

Demo III, FCS, UGCV, PerceptOR, MARS, TMR ...

Military Projects and Manufacturing

Military application of robotics is a prime technology development motivator

"Robotic support for the army promises to enhance military advantage and save the lives of soldiers. This is perhaps the most realistic motivator for future robotic development and may define the course of robotic technology in the 21st century."

-- Dr Hadi A. Akeel, FANUC Robotics NA

Autonomous Mobility for Materials Handling

- IMTI Goal: Provide material handling systems that change to meet any handling and movement requirement
- A new generation of AGVs will appear with free navigation, demand dispatch and flexible transport capability (tug, pallet, small items, manipulation)
- Impact on batch manufacturing (e.g. aerospace) will be significant

Interoperability

- Lack of interoperability costs auto manufacturers $200-400M per vehicle program
- An aerospace manufacturer reported that it took 100 man years to integrate $10M in capital equipment
- Seamless data flow essential for realization of “12 month” car

Open Architectures

- Target Customers: automotive and aerospace manufacturers and their control vendors
- Our collaboration is through industry groups
  - Open Modular Architecture Controller (OMAC)
  - Robotic Industries Association (RIA)
  - Metrology Automation Association (MAA)
  - American Welding Society (AWS)

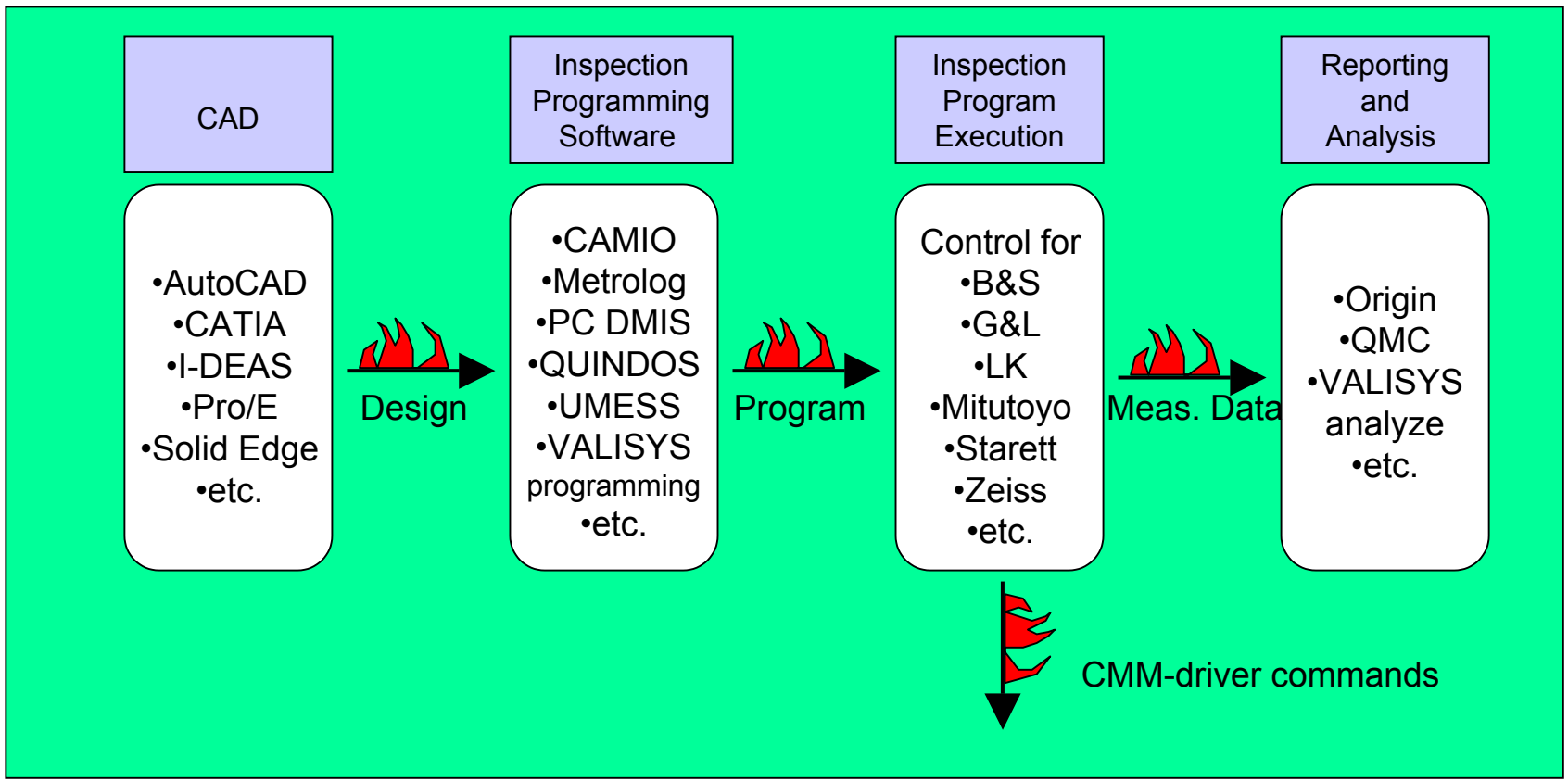
Open Modular Architecture Controls OMAC USERS GROUP

MAA

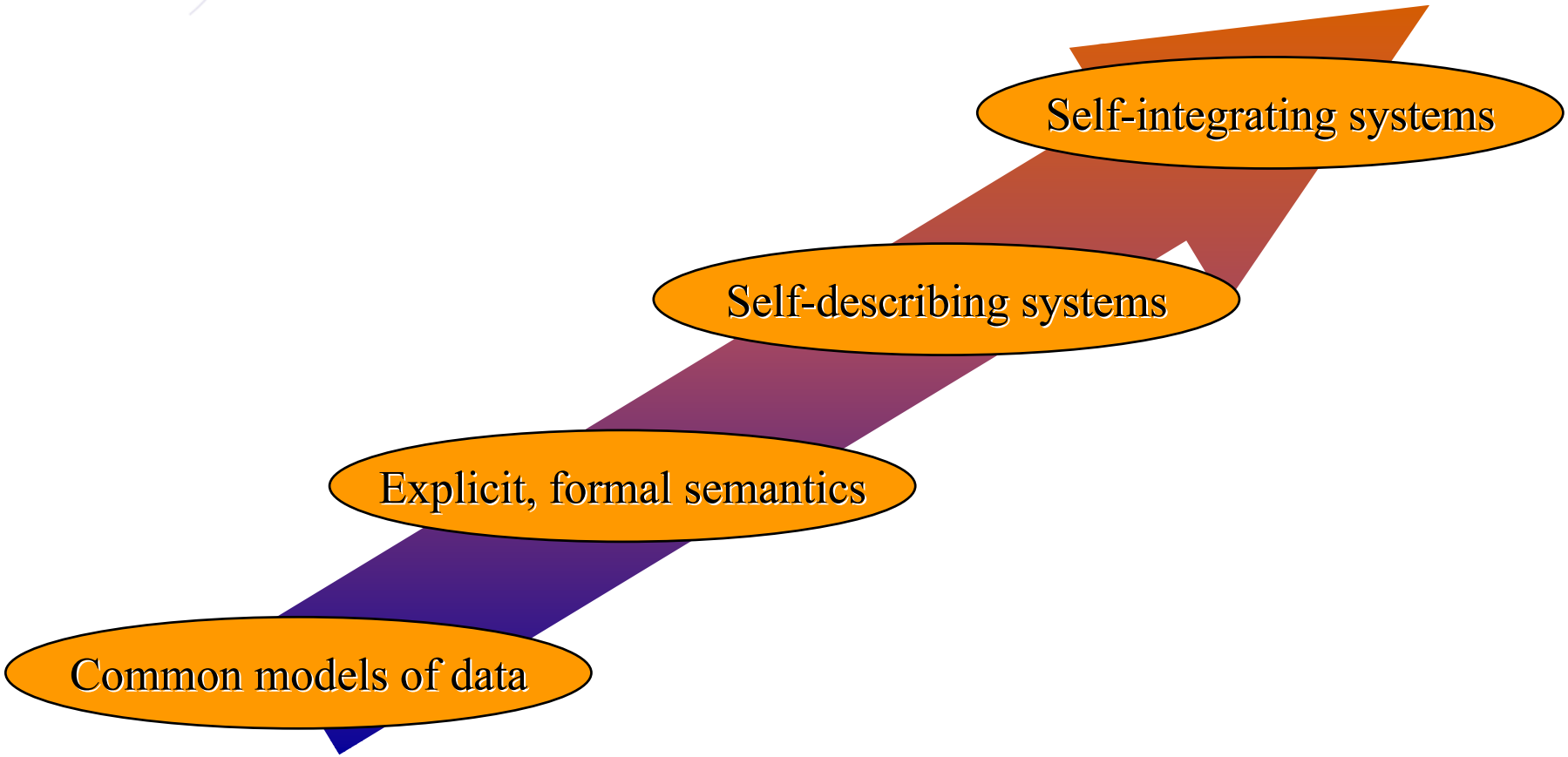
ria

American Welding Society
Gateway to the World of Welding

“Hot” Metrology Interfaces



Future Direction



Conclusion

- Intelligent control will enable major changes in manufacturing processes, material handling and overall system integration over the next twenty years
- Impact will be tens of billions of dollars and will determine survival in many global markets
- This has to be considered a major “game changer” over next twenty years